



# Low Voltage SOT-23 Temperature Sensors

## ADT41/ADT42/ADT43

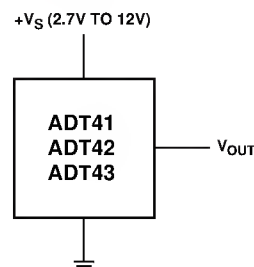
### FEATURES

- Low Voltage Operation (2.7 V to 12 V)
- Calibrated Directly in  $^{\circ}\text{C}$
- 10 mV/ $^{\circ}\text{C}$  Scale Factor (20 mV/ $^{\circ}\text{C}$  on ADT43)
- $\pm 2^{\circ}\text{C}$  Accuracy Over Temperature (typ)
- $\pm 0.5^{\circ}\text{C}$  Linearity (typ)
- Stable with Large Capacitive Loads
- Specified  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ , Operation to  $+150^{\circ}\text{C}$
- Less than 50  $\mu\text{A}$  Quiescent Current
- Low Self-Heating

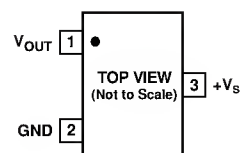
### APPLICATIONS

- Environmental Control Systems
- Thermal Protection
- Industrial Process Control
- Fire Alarms
- Power System Monitors
- CPU Thermal Management

### FUNCTIONAL BLOCK DIAGRAM



### PACKAGE AVAILABLE RT-3 (SOT-23 Package)



### GENERAL DESCRIPTION

The ADT41, ADT42 and ADT43 are low voltage, precision centigrade temperature sensors. They provide a voltage output that is linearly proportional to Celsius (Centigrade) temperature. The ADT41/ADT42/ADT43 do not require any external calibration to provide typical accuracies of  $\pm 1^{\circ}\text{C}$  at  $+25^{\circ}\text{C}$  and  $\pm 2^{\circ}\text{C}$  over the  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  temperature range. The low output impedance of the ADT41/ADT42/ADT43, linear output and precise calibration simplify interfacing to temperature control circuitry and A/D converters. All three devices are intended for single supply operation from 2.7 V to 12 V maximum. Supply current runs well below 50  $\mu\text{A}$ , providing very low self-heating—less than  $0.1^{\circ}\text{C}$  in still air. The ADT41 is functionally compatible

with the LM35/LM45 and provides a 250 mV output at  $+25^{\circ}\text{C}$ . The ADT41 reads temperatures from  $+10^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ . The ADT42 is specified from  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ , provides a 750 mV output at  $25^{\circ}\text{C}$  and operates to  $+125^{\circ}\text{C}$  from a single 2.7 V supply. Both the ADT41 and ADT42 have an output scale factor of 10 mV/ $^{\circ}\text{C}$ . The ADT43 is intended for applications over the range  $+5^{\circ}\text{C}$  to  $+100^{\circ}\text{C}$ , and provides an output scale factor of 20 mV/ $^{\circ}\text{C}$ . The ADT43 provides a 500 mV output at  $+25^{\circ}\text{C}$ . Operation extends to  $+150^{\circ}\text{C}$  with reduced accuracy for all devices when operating from a 12 V supply.

The ADT41/ADT42/ADT43 are all available in the low cost 3-lead SOT-23 surface mount package.

REV. 0

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# ADT41/ADT42/ADT43G—SPECIFICATIONS

( $V_S = +2.7\text{ V to }+5.5\text{ V}$ ,  $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$   
unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
<b>ACCURACY</b>						
ADT41/ADT42/ADT43G		$T_A = +25^\circ\text{C}$		$\pm 1$	$\pm 3$	$^\circ\text{C}$
ADT41/ADT42/ADT43G		Over Rated Temperature		$\pm 2$	$\pm 4$	$^\circ\text{C}$
Scale Factor, ADT41		$+10^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		+10	+9.8/+10.2	mV/ $^\circ\text{C}$
Scale Factor, ADT42		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		+10	+9.8/+10.2	mV/ $^\circ\text{C}$
Scale Factor, ADT43		$+5^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$		+20	+19.6/+20.4	mV/ $^\circ\text{C}$
		$+5^\circ\text{C} \leq T_A \leq +100^\circ\text{C}$		+20	+19.6/+20.4	mV/ $^\circ\text{C}$
		$3.0\text{ V} \leq +V_S \leq 5.5\text{ V}$				
Load Regulation		$0\text{ }\mu\text{A} \leq I_L \leq 50\text{ }\mu\text{A}$		1	20	m $^\circ\text{C}/\mu\text{A}$
Power Supply Rejection Ratio	PSRR	$T_A = +25^\circ\text{C}$		30	100	m $^\circ\text{C}/\text{V}$
		$3.0\text{ V} \leq +V_S \leq 5.5\text{ V}$		50		m $^\circ\text{C}/\text{V}$
Linearity				0.5		$^\circ\text{C}$
Long-Term Stability		$T_A = +150^\circ\text{C}$ for 1 kHrs		0.4		$^\circ\text{C}$
<b>OUTPUT</b>						
ADT41 Output Voltage		$T_A = +25^\circ\text{C}$		250		mV
ADT42 Output Voltage		$T_A = +25^\circ\text{C}$		750		mV
ADT43 Output Voltage		$T_A = +25^\circ\text{C}$		500		mV
Output Voltage Range			100		2000	mV
Output Load Current	$I_L$		0	—	100	$\mu\text{A}$
Short-Circuit Current	$I_{SC}$	Note 1			250	$\mu\text{A}$
Capacitive Load Driving	$C_L$	No Oscillations <sup>1</sup>	1000	10000		pF
Device Turn-On Time		Output Within $\pm 1^\circ\text{C}$		0.5	1	ms
		100 k $\Omega$    100 pF Load <sup>2</sup>				
<b>POWER SUPPLY</b>						
Supply Range	$V_S$		2.7		12	V
Supply Current	$I_{SY}$	Unloaded			50	$\mu\text{A}$

## NOTES

<sup>1</sup>Guaranteed but not tested.

<sup>2</sup>Does not consider errors caused by self-heating.

Specifications subject to change without notice.

Package Type	$\theta_{JA}$	$\theta_{JC}$	Units
SOT-23 (RT Suffix)	300	180	$^\circ\text{C}/\text{W}$

## NOTE

$\theta_{JA}$  is specified for device mounted on PCB.

## ABSOLUTE MAXIMUM RATINGS\*

Supply Voltage ..... +13.2 V  
Output Pin .....  $\text{GND} \leq V_{OUT} \leq +V_S$   
Operating Temperature Range .....  $-55^\circ\text{C}$  to  $+150^\circ\text{C}$   
Dice Junction Temperature .....  $+175^\circ\text{C}$   
Storage Temperature Range .....  $-65^\circ\text{C}$  to  $+160^\circ\text{C}$   
Lead Temperature (Soldering, 60 sec) .....  $+300^\circ\text{C}$

## \*CAUTION

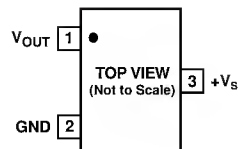
- Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation at or above this specification is not implied. Exposure to the above maximum rating conditions for extended periods may affect device reliability.
- Digital inputs are protected; however, permanent damage may occur on unprotected units from high energy electrostatic fields. Keep units in conductive foam or packaging at all times until ready to use. Use proper antistatic handling procedures.
- Remove power before inserting or removing units from their sockets.

## ORDERING GUIDE

Model	Accuracy at $25^\circ\text{C}$ ( $^\circ\text{C}$ max)	Linear Operating Temperature Range	Package Option*
ADT41GRT	$\pm 3.0$	$+10^\circ\text{C}$ to $+125^\circ\text{C}$	RT-3
ADT42GRT	$\pm 3.0$	$-40^\circ\text{C}$ to $+125^\circ\text{C}$	RT-3
ADT43GRT	$\pm 3.0$	$+5^\circ\text{C}$ to $+100^\circ\text{C}$	RT-3

\*RT = Surface Mount (SOT-23).

## PIN CONFIGURATION (SOT-23)



# Typical Performance Characteristics–ADT41/ADT42/ADT43

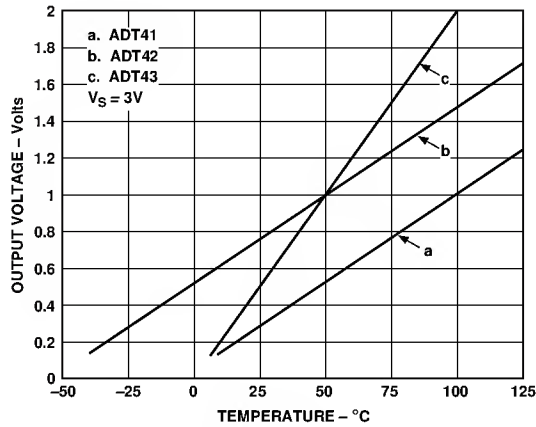


Figure 1. Output Voltage vs. Temperature

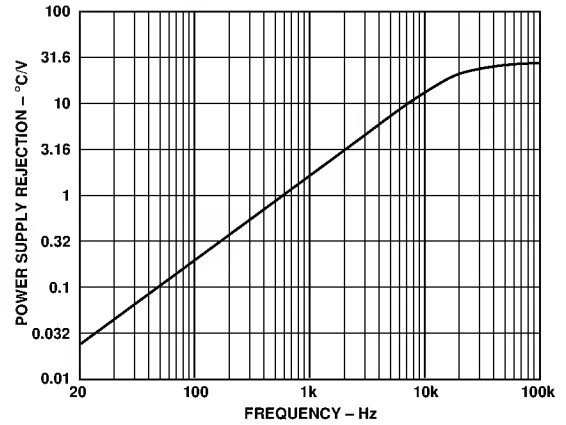


Figure 4. Power Supply Rejection vs. Frequency

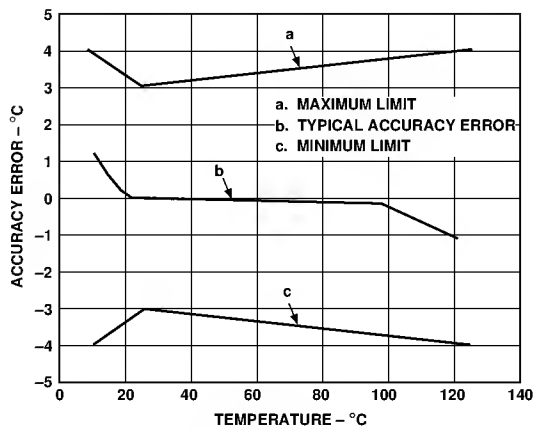


Figure 2. Accuracy Error vs. Temperature

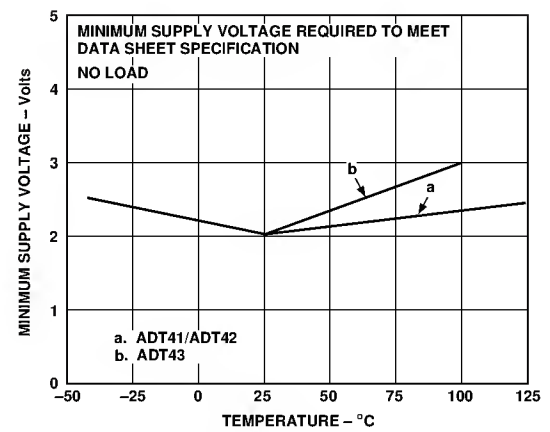


Figure 5. Minimum Supply Voltage vs. Temperature

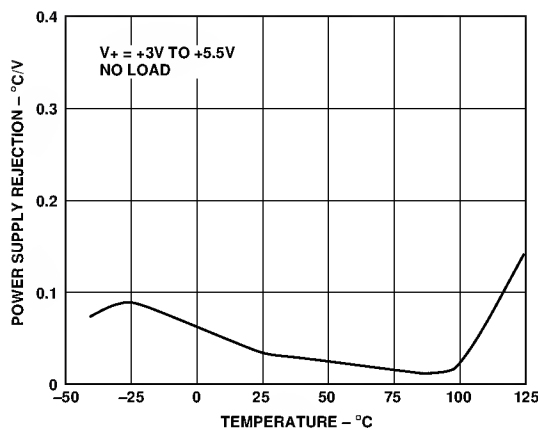


Figure 3. Power Supply Rejection vs. Temperature

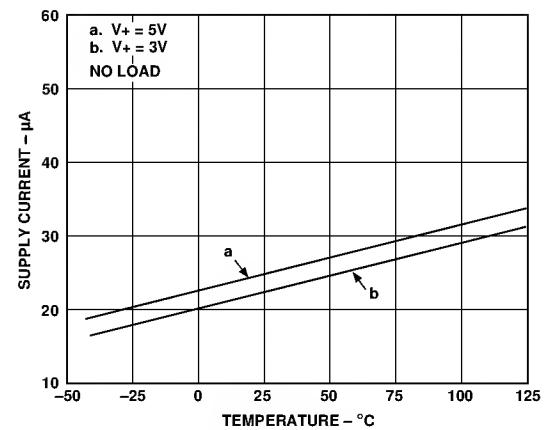


Figure 6. Supply Current vs. Temperature

# ADT41/ADT42/ADT43

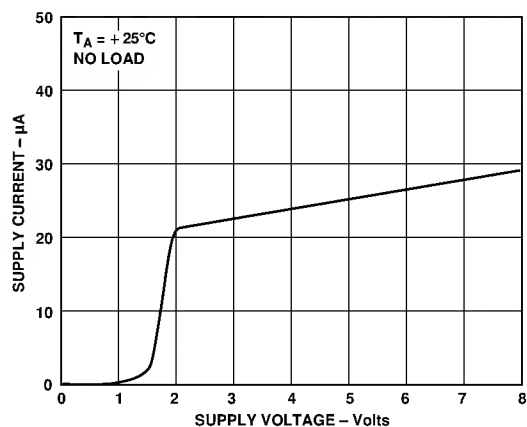


Figure 7. Supply Current vs. Supply Voltage

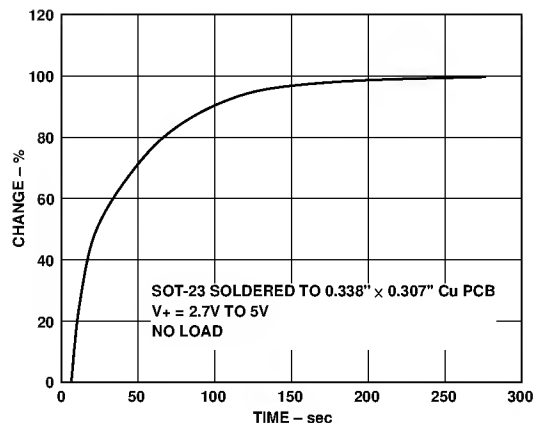


Figure 10. Thermal Response Time in Still Air

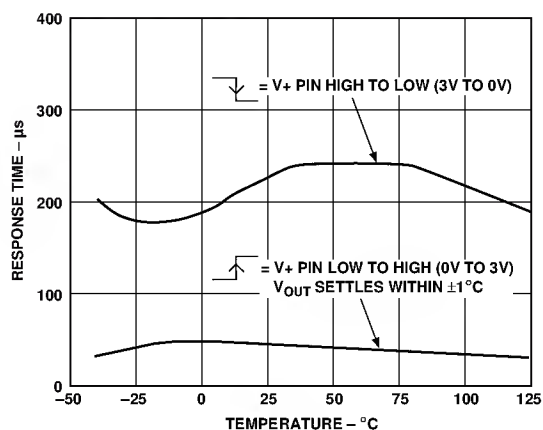


Figure 8.  $V_{OUT}$  Response Time for  $V_{+}$  Power-Up/Power-Down vs. Temperature

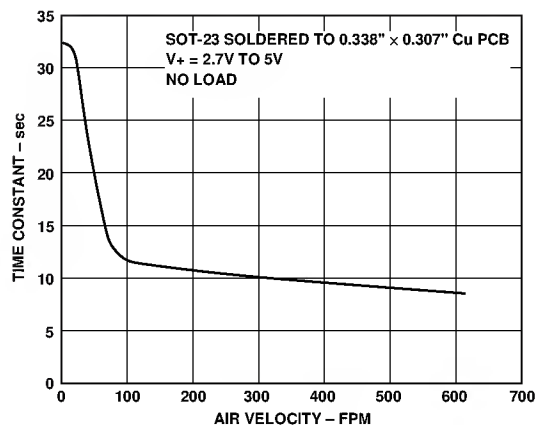


Figure 11. Thermal Response Time in Forced Air

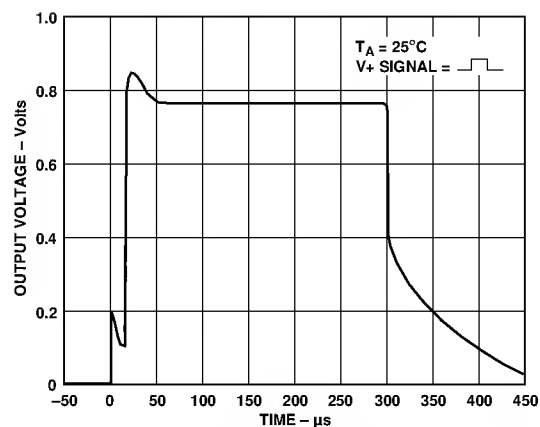


Figure 9.  $V_{OUT}$  Response Time to Power-On vs. Time

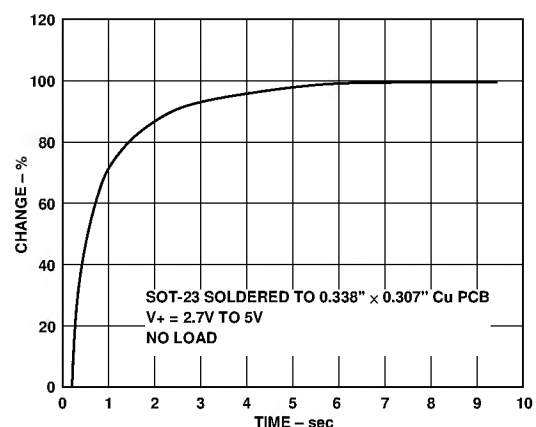


Figure 12. Thermal Response Time in Stirred Oil Bath

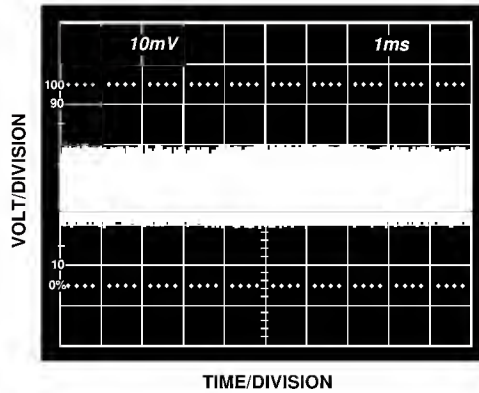


Figure 13. Temperature Sensor Wideband Output Noise Voltage. Gain = 100, BW = 157 kHz

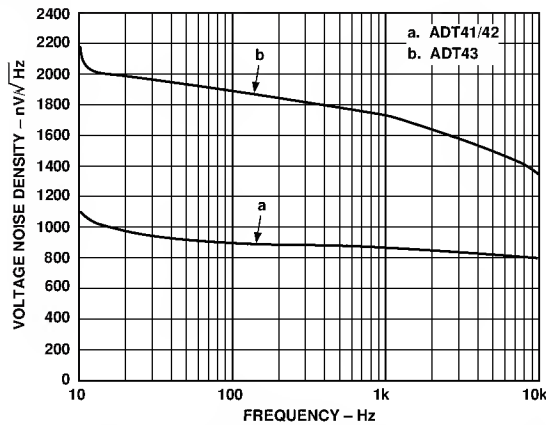


Figure 14. Voltage Noise Spectral Density vs. Frequency

## FUNCTIONAL DESCRIPTION

An equivalent circuit for the ADT4x family of micropower, centigrade temperature sensors is shown in Figure 15. At the heart of the temperature sensor is a bandgap core, comprised of transistors Q1 and Q2, biased by Q3 to approximately 8  $\mu$ A. The bandgap core operates both Q1 and Q2 at the same collector current level; however, since the emitter area of Q1 is 10 times that of Q2, Q1's  $V_{BE}$  and Q2's  $V_{BE}$  are not equal by the following relationship:

$$\Delta V_{BE} = V_T \times \ln \left( \frac{A_{E,Q1}}{A_{E,Q2}} \right)$$

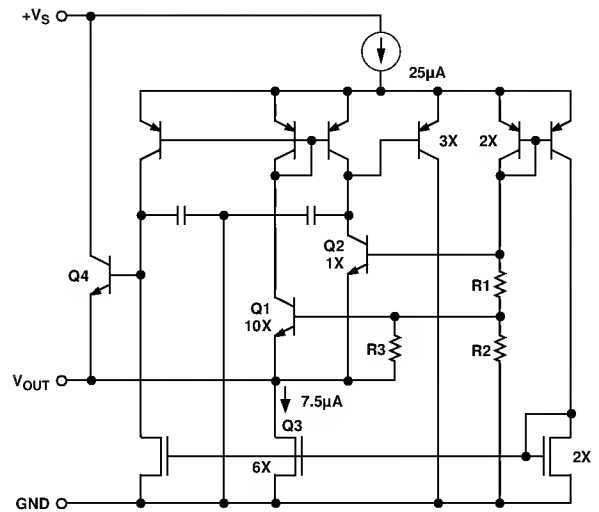


Figure 15. Temperature Sensor Simplified Equivalent Circuit

Resistors R1 and R2 are used to scale this result to produce the output voltage transfer characteristic of each temperature sensor and, simultaneously, R2 and R3 are used to scale Q1's  $V_{BE}$  as an offset term in  $V_{OUT}$ . Table I summarizes the differences between the three temperature sensors' output characteristics:

Table I. ADT4x Output Characteristics

Sensor	Offset Voltage (V)	Output Voltage Scaling (mV/°C)	Output Voltage @ +25°C
ADT41	0	10	250 mV
ADT42	0.5	10	750 mV
ADT43	0	20	500 mV

The output voltage of the temperature sensor is available at the emitter of Q4, which buffers the bandgap core and provides load current drive. Q4's current gain, working with the available base current drive from the previous stage, sets the short-circuit current limit of these devices to 250  $\mu$ A.

# ADT41/ADT42/ADT43

## APPLICATIONS SECTION

### Mounting Considerations

If the ADT4x temperature sensors are thermally attached and protected, they can be used in any temperature measurement application where the maximum temperature range of the medium is between  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ . Properly cemented or glued to the surface of the medium, these sensors will be within  $0.01^{\circ}\text{C}$  of the surface temperature. Caution should be exercised as any wiring to the device can act as heat pipes, introducing errors if the surrounding air-surface interface is not isothermal. Avoiding this condition is easily achieved by dabbing the leads of the temperature sensor and the hookup wires with a bead of thermally conductive epoxy. This will ensure that the ADT4x die temperature is not affected by the surrounding air temperature.

These temperature sensors, as well as any associated circuitry, should be kept insulated and dry to avoid leakage and corrosion. In wet or corrosive environments, any electrically isolated metal or ceramic well can be used to shield the temperature sensors. Condensation at very cold temperatures can cause errors and should be avoided by sealing the device using electrically non-conductive epoxy paints or dips, or any one of many printed circuit board coatings and varnishes.

### Thermal Environment Effects

The thermal environment in which the ADT4x sensors are used determines two important characteristics: self-heating effects and thermal response time. Illustrated in Figure 16 is a thermal model of the ADT4x temperature sensors, which is useful in understanding these characteristics.

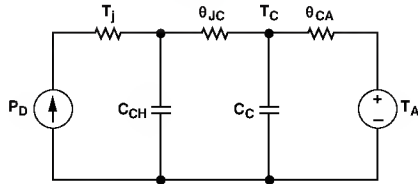


Figure 16. ADT4x Thermal Circuit Model

In the SOT-23 package, the thermal resistance junction-to-case,  $\theta_{JC}$ , is  $180^{\circ}\text{C/W}$ . The thermal resistance case-to-ambient,  $\theta_{CA}$ , is the difference between  $\theta_{JA}$  and  $\theta_{JC}$ , and is determined by the characteristics of the thermal connection. The temperature sensor's power dissipation, represented by  $P_D$ , is the product of the total voltage across the device and its total supply current (including any current delivered to the load). The rise in die temperature above the medium's ambient temperature is given by:

$$T_J = P_D \times (\theta_{JC} + \theta_{CA}) + T_A$$

Thus, the die temperature rise of an ADT41 "RT" package mounted into a socket in still air at  $25^{\circ}\text{C}$  and driven from a  $+5\text{ V}$  supply is less than  $0.04^{\circ}\text{C}$ .

The transient response of the ADT4x sensors to a step change in the temperature is determined by the thermal resistances and the thermal capacities of the die,  $C_{CH}$ , and the case,  $C_C$ . The thermal capacity of the case,  $C_C$ , varies with the measurement medium since it includes anything that is in direct contact with the package. In all practical cases, the thermal capacity of the case is the limiting factor in the thermal response time of the sensor and can be represented by a single-pole RC-time con-

stant response. Figures 11 to 13 illustrate the thermal response time of the ADT4x sensors under various conditions. The thermal time constant of a temperature sensor is defined to be the time required for the sensor to reach 63.2% of the final value for a step change in the temperature.

### Basic Temperature Sensor Connections

The circuit in Figure 17 illustrates the basic circuit configuration for the ADT4x family of temperature sensors.

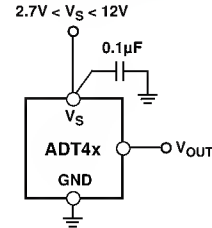


Figure 17. Basic Temperature Sensor Circuit Configuration

Note the  $0.1\text{ }\mu\text{F}$  bypass capacitor on the input. This capacitor should be a ceramic type, have very short leads (surface mount would be preferable), and located as close a physical proximity to the temperature sensor supply pin as practical. Since these temperature sensors operate on very little supply current and could be exposed to very hostile electrical environments, it is important to minimize the effects of RFI (Radio-Frequency Interference) on these devices. The effect of RFI on these temperature sensors in specific and analog ICs in general is manifested as abnormal dc shifts in the output voltage due to the rectification of the high frequency ambient noise by the IC. In those cases where the devices are operated in the presence of high frequency radiated or conducted noise, a large value tantalum capacitor ( $>2.2\text{ }\mu\text{F}$ ) placed across the  $0.1\text{ }\mu\text{F}$  ceramic may offer additional noise immunity.

### Fahrenheit Thermometers

Although the ADT4x temperature sensors are centigrade temperature sensors, a few components can be used to convert the output voltage and transfer characteristics to read Fahrenheit temperatures directly. Shown in Figure 18a is an example of a simple Fahrenheit thermometer using either the ADT41 or the ADT43. This circuit can be used to sense temperatures from  $41^{\circ}\text{F}$  to  $257^{\circ}\text{F}$  with an output transfer characteristic of  $1\text{ mV}/^{\circ}\text{F}$  using the ADT41 and from  $41^{\circ}\text{F}$  to  $212^{\circ}\text{F}$  using the ADT43 with an output characteristic of  $2\text{ mV}/^{\circ}\text{F}$ . This particular approach does not lend itself well to the ADT42 because of its inherent  $0.5\text{ V}$  output offset. The circuit is constructed with an AD589, a  $1.23\text{ V}$  voltage reference, and four resistors whose values for each sensor are shown in the figure table. The scaling of the output resistance levels was to ensure minimum output loading on the temperature sensors. An generalized expression for the circuit's transfer equation is given by:

$$V_{OUT} = \left( \frac{R1}{R1 + R2} \right) (ADT41) + \left( \frac{R3}{R3 + R4} \right) (AD589)$$

where: ADT41 = Output voltage of the ADT41, or the ADT43, at the measurement temperature,  $T_M$ , and  
AD589 = Output voltage of the reference =  $1.23\text{ V}$ .

Note that the output voltage of this circuit is not referenced to the circuit's common. If this output voltage were to be applied



directly to the input of an ADC, the ADC's common should be adjusted accordingly.

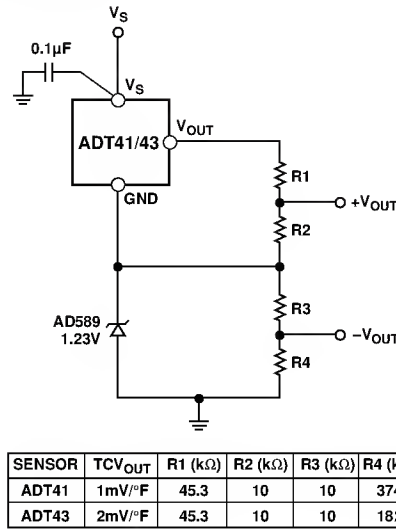


Figure 18a. ADT41/ADT43 Fahrenheit Thermometers

The same circuit principles can be applied to the ADT42, but because of the ADT42's inherent offset, the circuit uses two less resistors as shown in Figure 18b. In this circuit, the output voltage transfer characteristic is 1 mV/°F, but is referenced to the circuit's common; however, there is a 58 mV (58°F) offset in the output voltage. For example, the output voltage of the circuit would read 18 mV, if the ADT42 is placed in -40°F ambient environment, and 315 mV at 257°F.

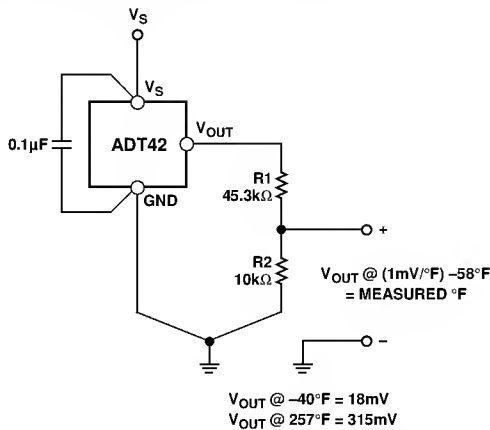


Figure 18b. ADT42 Fahrenheit Thermometer Version 1

At the expense of additional circuitry, the offset produced by the circuit in Figure 18b can be avoided by using the circuit in Figure 18c. In this circuit, the output of the ADT42 is conditioned by a single-supply, micropower op amp, the OP193. Although the entire circuit operates from a single +3 V supply, the output voltage of the circuit reads the temperature directly with a transfer characteristic of 1 mV/°F, without offset. This is accomplished through the use of an ADM660, a supply voltage inverter. The +3 V supply is inverted and applied to the OP193's V- terminal. Thus, for a temperature range between -40°F and 257°F, the output of the circuit reads -40 mV to 257 mV. A general expression for the circuit's transfer equation is given by:

$$V_{OUT} = \left( \frac{R6}{R5 + R6} \right) \left( 1 + \frac{R4}{R3} \right) (ADT42) - \left( \frac{R4}{R3} \right) \left( \frac{V_S}{2} \right)$$

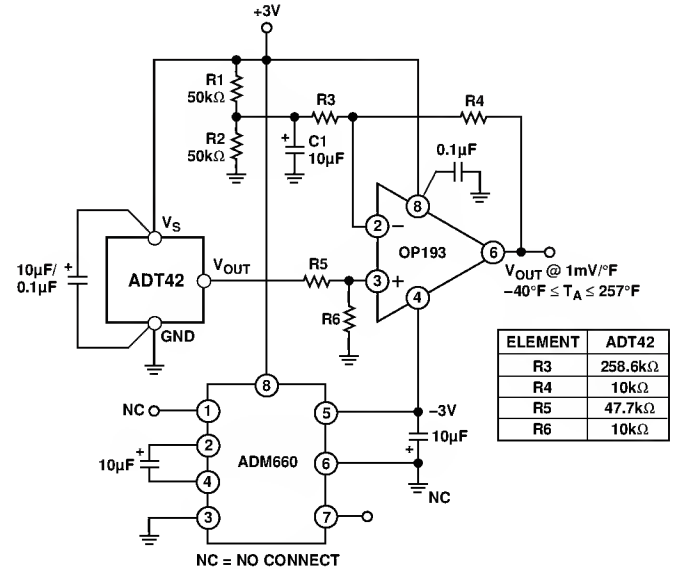


Figure 18c. ADT42 Fahrenheit Thermometer Version 2

## Average and Differential Temperature Measurement

In many commercial and industrial environments, temperature sensors are often used to measure the average temperature in a building or the difference in temperature between two locations on a factory floor or in an industrial process. The circuits in Figures 19a and 19b demonstrate an inexpensive approach to average and differential temperature measurement. In Figure 19a, an OP193 is used to amplify the stepped down averaged output of three temperature sensors to produce an output voltage scaled to 10 mV/°C (20 mV/°C for ADT43), which represents the average temperature at three locations. The circuit can be extended to as many temperature sensors as required as long as the circuit's transfer equation is maintained. In this application, it is recommended that one temperature sensor type be used throughout the circuit; otherwise, the output voltage of the circuit will not produce an accurate reading of the various ambient conditions.

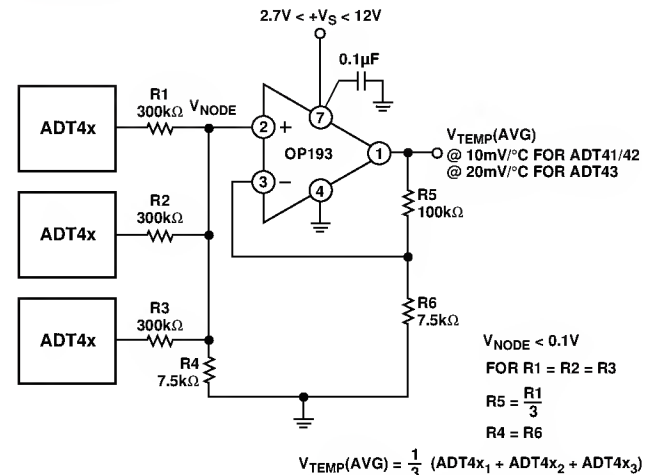


Figure 19a. Configuring Multiple Sensors for Average Temperature Measurements

## ADT41/ADT42/ADT43

The circuit in Figure 19b illustrates how a pair of ADT42 sensors can be used with an OP193 configured as a difference amplifier to read the difference in temperature between two locations. In these applications, it is always possible that one temperature sensor would be reading a temperature below that of the other sensor. To accommodate this condition, the output of the OP193 is offset to a voltage at one-half the supply via R5 and R6. Thus, the output voltage of the circuit is measured relative to this point, as shown in the figure. Using the ADT42, the output voltage of the circuit is scaled by 10 mV/°C. To minimize error in the difference between the two measured temperatures, a common, readily available thin-film resistor network is used for R1–R4.

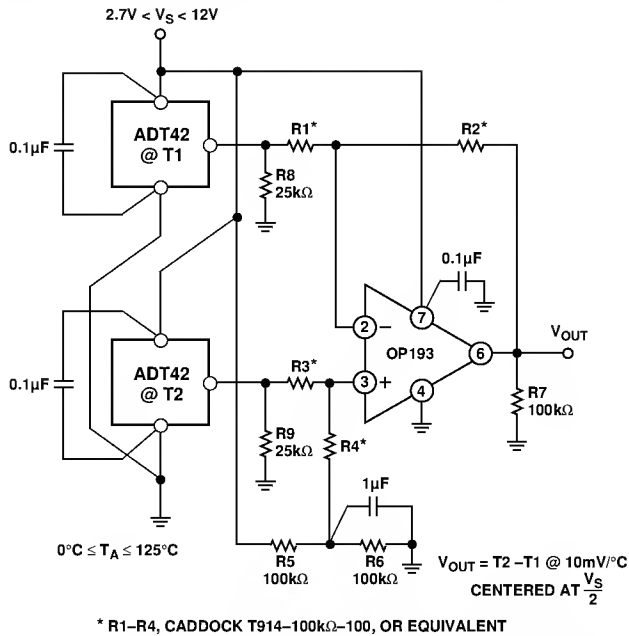


Figure 19b. Configuring Multiple Sensors for Differential Temperature Measurements

### Microprocessor Interrupt Generator

These inexpensive temperature sensors can be used with a voltage reference and an analog comparator to configure an interrupt generator useful in microprocessor applications. With the popularity of fast 486 and Pentium\* laptop computers, the need to indicate a microprocessor over-temperature condition has grown tremendously. The circuit illustrated in Figure 20 demonstrates one way to generate an interrupt using an ADT41, a CMP402 analog comparator, and an REF191, a 2 V precision voltage reference.

The circuit has been designed to produce a logic HIGH interrupt signal if the microprocessor temperature exceeds 80°C. This 80°C trip point was chosen arbitrarily (final value set by the microprocessor thermal reference design) and is set using an R3–R4 voltage divider of the REF191's output voltage. Since the output of the ADT41 is scaled by 10 mV/°C, the voltage at the CMP402's inverting terminal is set to 0.8 V.

Since temperature is a slowly moving quantity, the possibility for comparator chatter exists. To avoid this condition, hysteresis is used around the comparator. In this application, a hysteresis of 5°C about the trip point was arbitrarily chosen; the ultimate value for hysteresis should be determined by the end application. The output logic voltage swing of the comparator with R1 and R2 determine the amount of comparator hysteresis. Using a 3.3 V supply, the output logic voltage swing of the CMP402 is 2.6 V; thus, for a hysteresis of 5°C (50 mV @ 10 mV/°C), R1 is set to 20 kΩ and R2 is set to 1 MΩ. An expression for this circuit's hysteresis is given by:

$$V_{HYS} = \left( \frac{R1}{R2} \right) (V_{LOGIC SWING, CMP402})$$

Since the likelihood that this circuit would be used in close proximity to high speed digital circuits, R1 is split into equal values and a 1000 pF is used to form a low-pass filter on the output of the ADT41. Furthermore, to prevent high frequency noise from contaminating the comparator trip point, a 0.1 μF capacitor is used across R4.

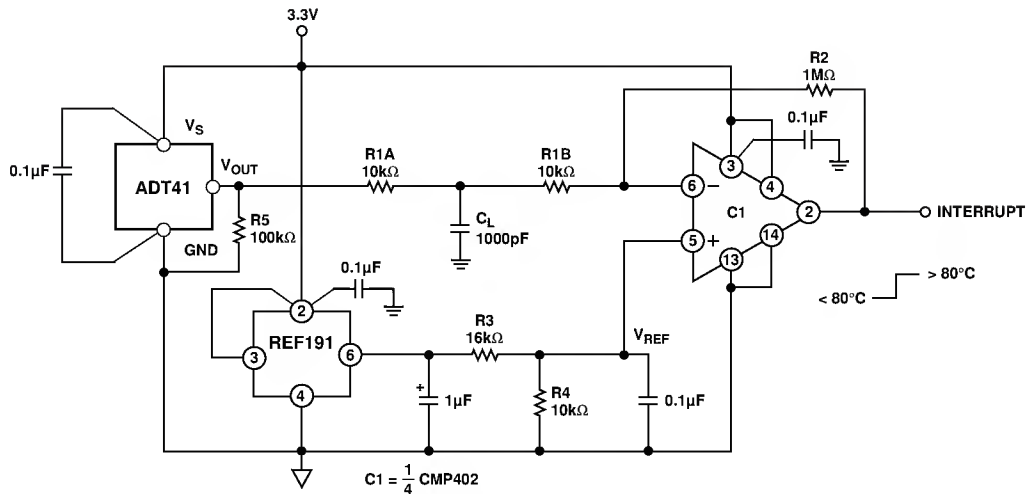


Figure 20. Pentium Over-Temperature Interrupt Generator



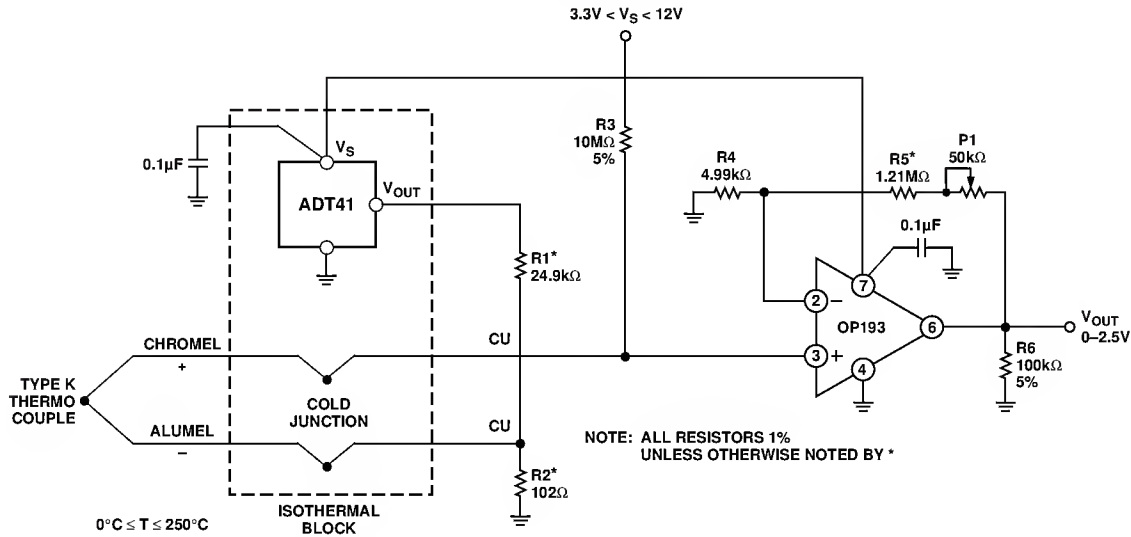


Figure 21. A Single-Supply, Type K Thermocouple Signal Conditioning Circuit with Cold-Junction Compensation

## Thermocouple Signal Conditioning with Cold-Junction Compensation

The circuit in Figure 21 conditions the output of a Type K thermocouple, while providing cold-junction compensation, for temperatures between 0°C and 250°C. The circuit operates from single +3.3 V to +12 V supplies and has been designed to produce an output voltage transfer characteristic of 10 mV/°C.

A Type K thermocouple exhibits a Seebeck coefficient of approximately 41  $\mu\text{V}/^\circ\text{C}$ ; therefore, at the cold junction, the ADT41 with a temperature coefficient of 10 mV/°C is used with R1 and R2 to introduce an opposing cold-junction temperature coefficient of  $-41 \mu\text{V}/^\circ\text{C}$ . This prevents the isothermal, cold-junction connection between the circuit's PCB tracks and the thermocouple's wires from introducing an error in the measured temperature. This compensation works extremely well for circuit ambient temperatures in the range of 20°C to 50°C. Over a 250°C measurement temperature range, the thermocouple produces an output voltage change of 10.151 mV. Since the required circuit's output full-scale voltage is 2.5 V, the gain of the circuit is set to 246.3. Choosing R4 equal to 4.99 k $\Omega$  sets R5 equal to 1.22 M $\Omega$ . Since the closest 1% value for R5 is 1.21 M $\Omega$ , a 50 k $\Omega$  potentiometer is used with R5 for fine trim of the full-scale output voltage. Although the OP193 is a superior single-supply, micropower operational amplifier, its output stage is not rail-to-rail; as such, the 0°C output voltage level is 0.1 V. If this circuit were to be digitized by a single-supply ADC, the ADC's common should be adjusted to 0.1 V accordingly.

## Using ADT4x Sensors in Remote Locations

In many industrial environments, sensors are required to operate in the presence of high ambient noise. These noise sources take on many forms; for example, SCR transients, relays, radio transmitters, arc welders, ac motors, et cetera. Furthermore, they may be used at considerable distance from the signal conditioning circuitry. These high noise environments are very typically in the form of electric fields, so the voltage output of the temperature sensor can be susceptible to contamination from these noise sources.

Illustrated in Figure 22 is a way to convert the output voltage of an ADT4x sensor into a current to be transmitted down a long

twisted-pair shielded cable to a ground referenced receiver. The temperature sensors do not possess the capability of high output current operation; thus, a garden variety PNP transistor is used to boost the output current drive of the circuit. As shown in the table, the values of R2 and R3 were chosen to produce an arbitrary full-scale output current of 2 mA. Lower values for the full-scale current are not recommended for the minimum-scale output current produced by the circuit could be contaminated by nearby ambient magnetic fields operating in vicinity of the circuit/cable pair. Because of the use of an external transistor, the minimum recommended operating voltage for this circuit is +5 V. Note, to minimize the effects of EMI (or RFI) both the circuit's and the temperature sensor's supply pins are bypassed with good quality, ceramic capacitors.

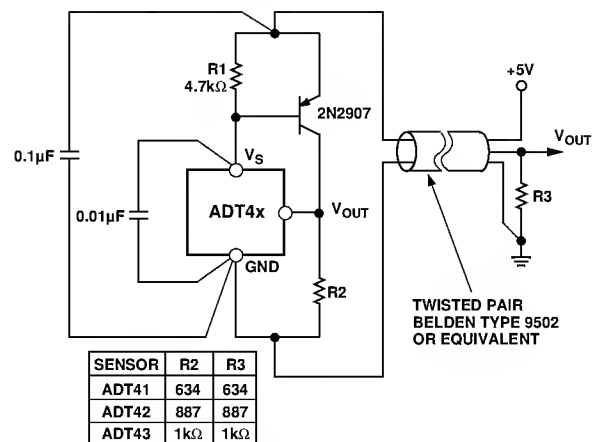


Figure 22. A Remote, Two-Wire Boosted Output Current Temperature Sensor

## A Temperature to 4–20 mA Loop Transmitter

In many process control applications, two-wire transmitters are used to convey analog signals through noisy ambient environments. These current transmitters use a “zero-scale” signal current of 4 mA that can be used to power the transmitter's signal conditioning circuitry. The “full-scale” output signal in these transmitters is 20 mA.

## ADT41/ADT42/ADT43

A circuit that transmits temperature information in this fashion is illustrated in Figure 24. Using an ADT4x as the temperature sensor, the output current is linearly proportional to the temperature of the medium. The entire circuit operates from the REF193's +3 V output. The REF193 requires no external trimming for two reasons: (1) the REF193's tight initial output voltage tolerance and (2) the low supply current of the ADT4x, the OP193 and the REF193. The entire circuit consumes less than 3 mA from a total budget of 4 mA. The OP193 regulates the output current to satisfy the current summation at the non-inverting node of the OP193. A generalized expression for the KCL equation at the OP193's Pin 3 is given by:

$$I_{OUT} = \left( \frac{1}{R_7} \right) \times \left( \frac{ADT4x \times R_3}{R_1} + \frac{V_{REF} \times R_3}{R_2} \right)$$

For each of the three temperature sensors, Table II provides the values for each of the components, P1, P2 and R1–R4:

**Table II. Circuit Element Values for Loop Transmitter**

Sensor	R1 (Ω)	P1 (Ω)	R2 (Ω)	P2 (Ω)	R3 (Ω)	R4 (Ω)
ADT41	97.6 k	5 k	1.58 M	100 k	140 k	56.2 k
ADT42	97.6 k	5 k	931 k	50 k	97.6 k	47 k
ADT43	97.6 k	5 k	10.5 k	500	84.5 k	8.45 k

The 4 mA offset trim is provided by P2, and P1 provides the circuit's full-scale gain trim at 20 mA. These two trims do not interact because the noninverting input of the OP193 is held at a virtual ground. The zero-scale and full-scale output currents of the circuit are adjusted according to the operating temperature range of each temperature sensor. The Schottky diode, D1, is required in this circuit to prevent loop supply power-on transients from pulling the noninverting input of the OP193 more than 300 mV below its inverting input. Without this diode, such transients could cause phase reversal of the operational amplifier and possible latchup of the transmitter. The loop supply voltage compliance of the circuit is limited by the maximum applied input voltage to the REF193 and is from +9 V to +18 V.

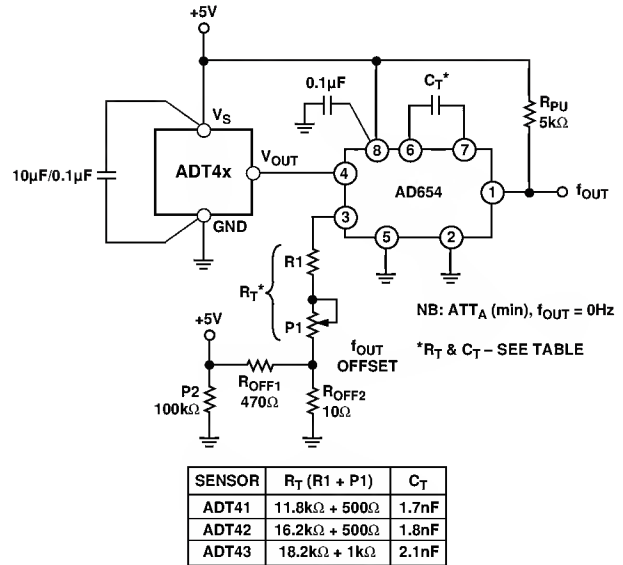
### A Temperature-to-Frequency Converter

Another common method of transmitting analog information from a remote location is to convert a voltage to an equivalent in the frequency domain. This is readily done with any of the low cost, monolithic voltage-to-frequency converters (VFCs) available. These VFCs feature a robust, open-collector output transistor for easy interfacing to digital circuitry. The digital signal produced by the VFC is less susceptible to contamination from external noise sources and line voltage drops because the only important information is the frequency of the digital signal. As

long as the conversions between temperature and frequency are accurately performed, the temperature data from the sensors can be reliably transmitted.

The circuit in Figure 23 illustrates a method by which the outputs of these temperature sensors can be converted to a frequency using the AD654. The output signal of the AD654 is a square wave that is proportional to the dc input voltage across Pins 4 and 3. The transfer equation of the circuit is given by:

$$f_{OUT} = \frac{V_{TMP} - V_{OFFSET}}{10 \times (R_T \times C_T)}$$



**Figure 23. A Temperature-to-Frequency Converter**

An offset trim network ( $f_{OUT} \text{ OFFSET}$ ) is included with this circuit to set  $f_{OUT}$  at 0 Hz when the temperature sensor's minimum output voltage is reached. Potentiometer P1 is required to calibrate the absolute accuracy of the AD654. The table in the figure illustrates the circuit element values for each of the three sensors. The nominal offset voltage required for 0 Hz output from the ADT41 is 50 mV; for the ADT42 and ADT43, the offset voltage required is 100 mV. In all cases for the circuit values shown, the output frequency transfer characteristic of the circuit was set at 50 Hz/°C. At the receiving end, a frequency-to-voltage converter (FVC) can be used to convert the frequency back to a dc voltage for further processing. One such FVC is the AD650.

For complete information on the AD650 and AD654, please consult the individual data sheets for those devices.

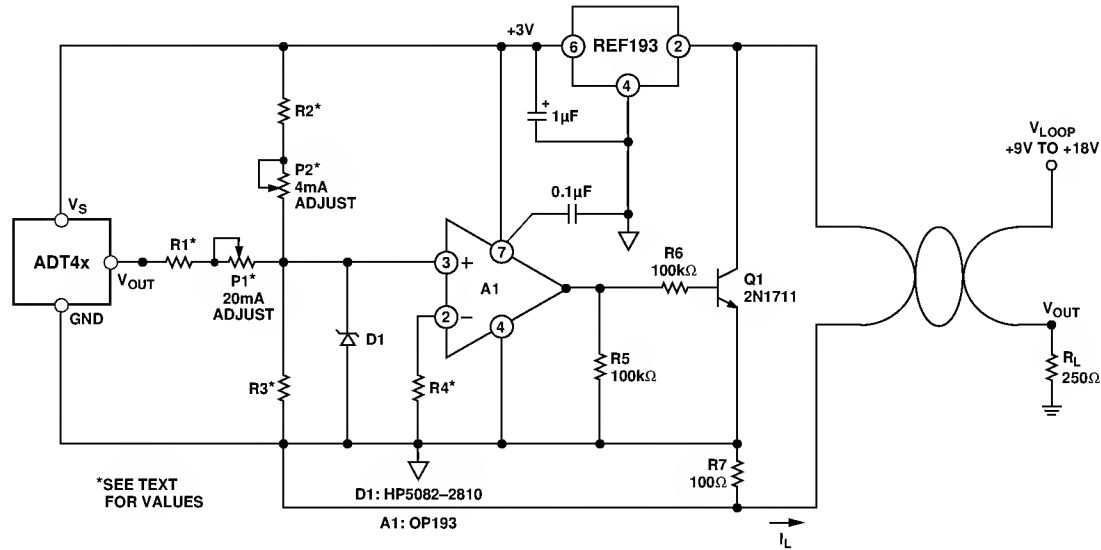
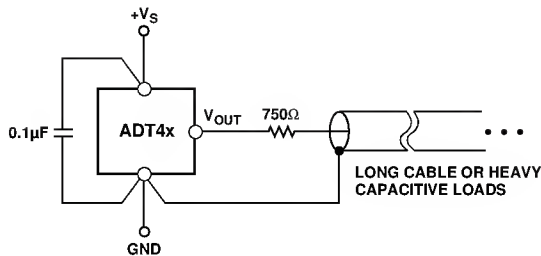


Figure 24. A Temperature to 4-to-20 mA Loop Transmitter

## Driving Long Cables or Heavy Capacitive Loads

Although the ADT4x family of temperature sensors is capable of driving capacitive loads up to 10,000 pF without oscillation, output voltage transient response times can be improved with the use of a small resistor in series with the output of the temperature sensor, as shown in Figure 25. As an added benefit, this resistor forms a low-pass filter with the cable's capacitance, which helps to reduce bandwidth noise. Furthermore, since the temperature sensor is likely to be used in environments where the ambient noise level can be very high, this resistor helps to prevent rectification by the devices of the high frequency noise. The combination of this resistor and the supply bypass capacitor offers the best protection.



*Figure 25. Driving Long Cables or Heavy Capacitive Loads*

### Commentary on Long-Term Stability

The concept of long-term stability has been used for many years to describe the amount by which an IC's parameter would shift during its lifetime, a concept that has been typically applied to both voltage references and monolithic temperature sensors. Unfortunately, integrated circuits cannot be evaluated at room temperature (25°C) for 10 years or so to determine this shift. As a result, manufacturers very typically perform accelerated lifetime testing of integrated circuits by operating ICs at elevated temperatures (between 125°C and 150°C) over a shorter period of time (typically, between 500 and 1000 hours).

As a result of this operation, the lifetime of an integrated circuit is significantly accelerated due to the increase in rates of reaction within the semiconductor material. A well understood, and

universal, model used by the semiconductor industry that relates the change in rates of reaction to a change in elevated temperatures is the Arrhenius model. From the Arrhenius model, an acceleration factor can be calculated and applied to the parameter specified. For example, this acceleration factor can be used to reduce a temperature sensor's long-term stability (e.g., 0.4°C after 1000 hours at  $T_j = 150^\circ\text{C}$ ) to an observed shift in that parameter at 25°C. For any semiconductor device, the acceleration factor is expressed as:

$$F = \exp \left[ \left( \frac{E_a}{k} \right) \times \left( \frac{1}{T_1} - \frac{1}{T_2} \right) \right]$$

where  $F$  = Calculated acceleration factor;

 $E_a$  = Activation energy in eV = 0.7 eV; $k = \text{Boltzmann's constant} = 8.63 \times 10^{-5} \text{ eV/K};$ 

$T_1$  = Test temperature in Kelvin,  $T_1 = 150^\circ\text{C} = 423.15\text{K}$ ;

$T_2$  = Desired operating temperature in Kelvin,

$$T_I = 25^{\circ}\text{C} = 298.15\text{K}$$

For example, if the desired operating temperature of an IC is 25°C and has been subjected to test temperature of 150°C, the acceleration factor is:

$$F = 3.23 \times 10^{-4}$$

With this background information, the ADT4x family's long-term stability can be mapped to what its equivalent observed shift would be at  $T_A = 25^\circ\text{C}$ . As quoted in the data sheet, the long-term stability of these temperature sensors after 1000 hours at  $150^\circ\text{C}$  is  $0.4^\circ\text{C}$ . This shift is equivalent to  $0.01^\circ\text{C}/\text{day}$  at  $T_J = 150^\circ\text{C}$ . To determine what the observed shift would be at  $T_A = 25^\circ\text{C}$  is a matter of applying the acceleration factor calculated above to this result:

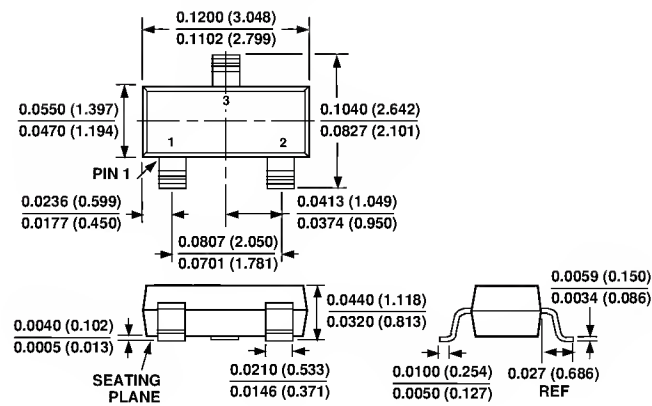
$$0.01^{\circ}\text{C}/\text{day} \times 3.23 \times 10^{-4} = 0.003 \text{ } m^{\circ}\text{C}/\text{day} @ 25^{\circ}\text{C}$$

Thus, if any of the ADT4x devices were to be used at 25°C, the observed shift would be no more than 0.003 m°C per day, or 0.1 m°C per month. Calculating the observed shift for any other operating temperature is simply a matter of calculating a new acceleration factor.

ADT41/ADT42/ADT43

OUTLINE DIMENSIONS  
Dimensions shown in inches and (mm).

3-Lead Plastic Surface Mount Package  
(RT-3)



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